IMPLICATION OF THE WEAK PHASE β MEASURED IN $B \to \rho\gamma$ DECAY

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We explore the exclusive $B^0 \to \rho^0\gamma$ decay to obtain the time-dependent CP asymmetry in $b \to d\gamma$ decay process. We find that the complex RL and RR mass insertion to the squark sector in the MSSM can lead to a large deviation of CP asymmetry from that predicted in the Standard Model.

1 Introduction

In the B meson system, it is strongly required to find a new observables for the CP violation in a way independent of the B^0–$\bar{B}^0$ mixing since the observed CP violating asymmetry appears only through the mixing so far. Moreover, we may expect that new physics can influence the $\Delta B = 1$ penguin decays in a different way from the $\Delta B = 2$ mixing, e.g. the controversial deviation of the recent measurement of $\sin 2\beta$ in $B \to \phi K$ decay from that in $B \to J/\psi K_S$ decays [1], which implies an evidence of a new physics effect beyond the SM [2].

The Cabibbo-suppressed $b \to d\gamma$ decay provides us a new chance to study the CP violation in a way independent of the mixing. In the present work, we consider the time-dependent CP asymmetry in the neutral $B^0 \to \rho^0\gamma$ decay. Although we will be able to determine V_{td} from the inclusive $B \to X_d\gamma$ decay in a theoretically clean way [3], it suffers from large $B \to X_s\gamma$ background in the experiment. The charged $B^\pm \to \rho^\pm\gamma$ decay mode provides clean signal and has a branching ratio twice larger than that of the neutral mode, by the isospin symmetry. However, the long-distance (LD) effect on the charged mode due to dominantly $W^\pm$-annihilation is very large (∼30 %), which contaminates the CP violating effect [4,5]. The exclusive $B \to \rho\gamma$ decays in the SM and the MSSM have been studied in the literature [6].

The photon has two helicity states γ_L and γ_R although we cannot discriminate them in the experiment. Since the time-dependent CP violating asymmetry is defined when both B and $\bar{B}$ mesons decay into a same state, there is no interference between final states with the definite helicity. In the SM, the operator which governs $b \to d\gamma$ decay is chiral and the conjugate operator is suppressed by m_d/m_b and the CP asymmetry also suppressed accordingly. Therefore the new physics beyond the SM is required for a large time-dependent CP asymmetry enough being observed in the experiment [7].

In this work, we consider the supersymmetric models which have non-diagonal elements of the squark mass matrices, parameterized by the mass insertions $(\delta_{ij})_{MN} \equiv (\tilde{m}^2_{ij})_{MN}/\tilde{m}^2$, where $\tilde{m}$ is the averaged squark mass, i and j are flavor indices and

M and N denote chiralities. The δ's are complex in general and provide new CP phases. To simplify our discussion, we consider only $(\delta_{13})_{RL}$ and $(\delta_{13})_{RR}$ dominating cases. In section 2, we describe the $B^0 \to \rho^0\gamma$ decay and the time-dependent CP asymmetry. The supersymmetric contributions are given in section 3 and the numerical results given in the section 4. We conclude in section 5.

2 CP asymmetry in $B^0 \to \rho^0\gamma$ decay

The relevant terms of the effective Hamiltonian for the $b \to d\gamma$ decay is written as

$$\mathcal{H}_{\rm eff} = \frac{4G_F}{\sqrt{2}} \sum_{q=u,c} \Bigg[\lambda_q \sum_{i=1,2} \left(C_i O_i^q + C_i' O_i'^q \right) , \\ -\lambda_t \left(C_7^{\rm eff} O_7 + C_7'^{\rm eff} O_7' \right) + \cdots \Bigg] , \quad (1)$$

where $\lambda_q = V_{qb}V_{qd}^*$, $O_1^q = (\bar{d}_L^\alpha \gamma_\mu q_L{}^\beta)(\bar{q}_L^\beta \gamma^\mu b_L{}^\alpha)$, $O_2^q = (\bar{d}_L\gamma_\mu q_L)(\bar{q}_L\gamma^\mu b_L)$, and $O_7 = (em_b/16\pi^2)\bar{d}_L\sigma_{\mu\nu}F^{\mu\nu}b_R$. The primed O_i' are their chiral conjugate operators. The effective Wilson coefficient $C_7^{(\prime)\rm eff}$ includes the effects of operator mixing.

We write the amplitudes for the final states of polarized photon as

$$\begin{aligned} A_L &\equiv \langle \rho\gamma_L | H_{\rm eff} | B^0 \rangle \sim C_7'^{\rm eff\,*} \lambda_t^* \langle \rho\gamma_L | O_7'^\dagger | B^0 \rangle, \\ A_R &\equiv \langle \rho\gamma_R | H_{\rm eff} | B^0 \rangle \sim C_7^{\rm eff\,*} \lambda_t^* \langle \rho\gamma_R | O_7^\dagger | B^0 \rangle, \\ \bar{A}_L &\equiv \langle \rho\gamma_L | H_{\rm eff} | \bar{B}^0 \rangle \sim C_7^{\rm eff} \lambda_t \langle \rho\gamma_L | O_7 | \bar{B}^0 \rangle, \\ \bar{A}_R &\equiv \langle \rho\gamma_R | H_{\rm eff} | \bar{B}^0 \rangle \sim C_7'^{\rm eff} \lambda_t \langle \rho\gamma_R | O_7' | \bar{B}^0 \rangle, \end{aligned} \quad (2)$$

up to the factor of $4G_F/\sqrt{2}$. We note that $\langle\rho\gamma_L|O_7|\bar{B}^0\rangle = \langle\rho\gamma_L|O_7'^\dagger|B^0\rangle$, and $\langle\rho\gamma_R|O_7'|\bar{B}^0\rangle = \langle\rho\gamma_R|O_7^\dagger|B^0\rangle$. In the SM, $C_7'^{\rm eff}$ is suppressed by the mass ratio m_d/m_b and so is the right polarized photon emission $b_L \to q_R\gamma_R$. For the neutral B meson decay, the LD contribution due to W-exchange is merely a few % from the QCD sum rule calculation [4,5], so it will be ignored in our analysis. We investigate the time-dependent CP asymmetry given by

$$A_{\rm CP}(t) = \frac{\bar{\Gamma} - \Gamma}{\bar{\Gamma} + \Gamma} \\ \equiv -\mathcal{C}\cos(\Delta m_B t) + \mathcal{S}\sin(\Delta m_B t), \quad (3)$$

where $\bar{\Gamma} = \Gamma(\bar{B}^0(t) \to \rho^0\gamma_L) + \Gamma(\bar{B}^0(t) \to \rho^0\gamma_R)$, $\Gamma = \Gamma(B^0(t) \to \rho^0\gamma_L) + \Gamma(B^0(t) \to \rho^0\gamma_R)$, since we cannot distinguish γ_L and γ_R in practice. The coefficients $\mathcal{C} = 0$ and

$$\mathcal{S} = \frac{|A_L|^2 {\rm Im}\lambda_L + |A_R|^2 {\rm Im}\lambda_R}{|A_L|^2 + |A_R|^2}, \quad (4)$$

with the parameter $\lambda_{L(R)}$ defined by

$$\lambda_{L(R)} \equiv \sqrt{\frac{M_{12}^*}{M_{12}}} \frac{\bar{A}_{L(R)}}{A_{L(R)}}. \quad (5)$$

The off-diagonal element M_{12} describes the B^0–$\bar{B}^0$ mixing and $A_{L(R)}$ does the $b \to d\gamma$ decays. We define $2\beta_{\rm mix} = {\rm Arg}\,(M_{12})$ and $2\beta_{\rm decay} = {\rm Arg}\left(\bar{A}_R/A_R\right) = {\rm Arg}\left(\bar{A}_L/A_L\right)$. Then the coefficient $\mathcal{S}$ is expressed by

$$\mathcal{S} = -\frac{2\,|C_7||C_7'|}{|C_7|^2 + |C_7'|^2} \sin(2\beta_{\rm mix} - 2\beta_{\rm decay}), \quad (6)$$

where we rewrite

$$2\beta_{\rm decay} = 2\beta_{\rm SM} + {\rm Arg}(C_7') - {\rm Arg}(C_7^*). \quad (7)$$

Note that we have an additional factor $2\,|C_7||C_7'|/(|C_7|^2 + |C_7'|^2)$, which can enhance or suppress $\mathcal{S}$ by the new physics effect $|C_7'|$.

3 SUSY contributions

By penguin diagrams with gluino-squark loop, the Wilson coefficients C_i' get contribution to produce γ_R at the matching scale $\mu = m_W$. After the RG evolution, we have $C_7^{\rm eff}(m_b) = C_7^{\rm SM}(m_b) = -0.31$ and

$$C_7'^{\rm eff}(m_b) = \frac{\sqrt{2}}{G_F V_{tb} V_{td}^*} \left(0.67\; C_7^{\rm SUSY}(m_W) \\ +0.09\; C_8^{\rm SUSY}(m_W) \right) , \quad (8)$$

where the SUSY contributions at $\mu = m_W$ are

$$C_7^{\rm SUSY} = \frac{4\alpha_s \pi Q_b}{3\tilde{m}^2} \Big[(\delta_{13})_{RR} M_4(x) \\ -(\delta_{13})_{RL} 4B_1(x) \frac{m_{\tilde{g}}}{m_b} \Big] , \quad (9)$$

$$C_8^{\rm SUSY} = \frac{\alpha_s\pi}{6\tilde{m}^2}\left[(\delta_{13})_{RR}(9M_3(x)-M_4(x)) + (\delta_{13})_{RL}\left(4B_1(x)-9\frac{B_2(x)}{x}\right)\frac{m_{\tilde g}}{m_b}\right],$$

with $x=(m_{\tilde g}/\tilde m)^2$ [9]. Note that the SUSY contribution is more sensitive to $(\delta_{13})_{RL}$ than $(\delta_{13})_{RR}$ due to the enhancement factor $m_{\tilde g}/m_b$. The loop functions $B_i(x)$ are found in the literature [9]. Since $\delta_{RL,RR}$ are complex in general, the Wilson coefficients $C'^{\rm eff}_7(m_b)$ has nontrivial phase which affects the phase of $\bar{A}/A$.

On the other hand, the B–$\bar{B}$ mixing is affected by the gluino-squark box diagrams in the MSSM. The relevant $\Delta B=2$ effective Hamiltonian with the supersymmetric contribution contains new scalar-scalar interaction operators $O'_{S2}=(\bar{d}_\alpha(1+\gamma_5)b_\alpha)(\bar{d}_\beta(1+\gamma_5)b_\beta)$, $O'_{S3}=(\bar{d}_\alpha(1+\gamma_5)b_\beta)(\bar{d}_\alpha(1+\gamma_5)b_\beta)$, when we introduce only the RL and RR mass insertions. The Wilson coefficient C_1 corresponding to the SM operator $O_1=(\bar{d}\gamma_\mu(1-\gamma_5)b)(\bar{d}\gamma_\mu(1-\gamma_5)b)$ consists of the SM part and the supersymmetric contributions, while C'_{S2} and C'_{S3} corresponding to the above operators are entirely supersymmetric. Their explicit expression at the scale $\mu=M_{\rm SUSY}$ can be found in Refs. [10,11]. The RG evolved Wilson coefficients from m_W to m_b scale ignoring the RG running effects between $M_{\rm SUSY}$ and m_W, are given in Ref. [12].

4 Numerical results

Figure 1 shows the quantity $\mathcal{S}$ as a function of the phase of $(\delta_{13})_{RL}$, φ, assuming $|(\delta_{13})_{RL}|=0.001$. We vary the weak phase γ from 0 to 2π. Hereafter we use the input parameters as follows: $m_B=5.3$ GeV, $m_t=174.3$ GeV, $m_b=4.6$ GeV, and $\alpha_s(m_Z)=0.118$. The decay constant $f_{B_d}=200\pm30$ MeV is the main source of the theoretical uncertainty and the bag parameters are those of Ref. [13]; $B_1=0.87$, $B_2=0.82$, $B_3=1.02$. The supersymmetric scale is taken to be $m_{\tilde g}\approx\tilde m\approx M_{\rm SUSY}\approx 500$ GeV. We require that the mass difference Δm_B and $\beta_{\rm mix}$ in $B\to J/\psi K$ decay should be within the experimental limit: $\Delta m_B=0.489\pm0.008\,{\rm ps}^{-1}$ [14] and $\sin 2\beta_{\rm mix}=0.734\pm0.055$ [1]. We do not use ${\rm Br}(B\to\rho/\omega\gamma)$ as a constraint since it involves a large theoretical uncertainty in the form factor. Instead, we assume a moderate upper bound on the branching ratio of the inclusive $B\to X_d\gamma$ decay ${\rm Br}(B\to X_d\gamma)<1.0\times10^{-5}$, following Ref. [11]. although the inclusive decay is not observed yet. The black region corresponds to the allowed values for the phase of $(\delta_{13})_{RL}$, while the grey (green) region denotes the parameter set which satisfies the Δm_B and $\sin 2\beta_{\rm mix}$ constraints but exceeds the bound on ${\rm Br}(B\to X_d\gamma)$. We find that large CP violating asymmetry is possible.

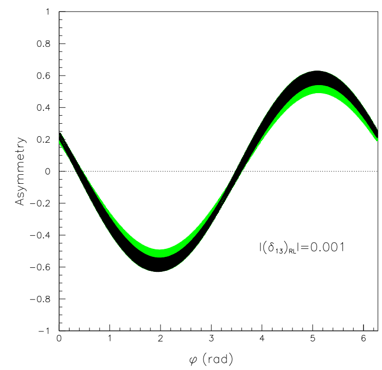

Figure 1. The time-dependent CP asymmetry $\mathcal{S}$ as a function of the phase of $(\delta_{13})_{RL}$. $|(\delta_{13})_{RL}|=0.001$ is assumed. The black region denotes allowed points while grey (green) region excluded points by the inclusive $b\to d\gamma$ branching ratio bound.

The plot of $\mathcal{S}$ with respect to $|(\delta_{13})_{RL}|$ is depicted in Fig. 2 when the phase φ is fixed to be zero. The black region and the grey (green) region are defined as in Fig. 1. We see that $|(\delta_{13})_{RL}|$ is strongly constrained by the inclusive branching ratio and a large CP violation is still possible even when $C'^{\rm eff}_7(m_b)$ is real. The branching ratio ${\rm Br}(B\to X_d\gamma)$ and CP asymmetry $\mathcal{S}$ provide the complimentary information on $(\delta_{13})_{RL}$.

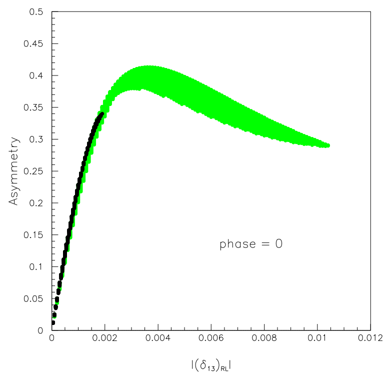

Figure 2. The time-dependent CP asymmetry $\mathcal{S}$ as a function of $|(\delta_{13})_{RL}|$. The phase of $(\delta_{13})_{RL}$ is assumed to be 0. The black region and the grey (green) region are defined in Fig. 1.

5 Concluding remarks

If we observe a sizable CP asymmetry in $B^0 \to \rho^0\gamma$ decay, it will be a clear evidence of the new physics beyond the SM. Although it is hardly expected that the time dependent CP asymmetry of $B^0 \to \rho^0\gamma$ will be measured in the present B-factory, it will be achieved in the next generation of B-factory with about 100 times more B mesons produced. Due to the agreement of the SM prediction with the present Δm_B data and the CP asymmetry in $B \to J/\psi K$ decay, we favor the new physics which contributes less to the B–$\bar{B}$ mixing but has a strong effect on the $b \to d\gamma$ penguin diagram. In this work, we showed that the RL mass insertion of squark mixing of the MSSM can produce a large CP asymmetry of $B^0 \to \rho^0\gamma$ decay process.

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